Appendix 2.5 B

Task 2.5 B: Disinfection Alternatives In Municipal Wastewater Reclamation

Submitted by:

Project Development Group
Orange County Water District
10500 Ellis Avenue
Fountain Valley 92728, California

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development and Demonstration (RD&D) organizations including individuals, businesses, utilities and public or private research institutions.

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- Building End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research

What follows is the final report for *Electrotechnologies for the production of potable water and the protection of the environment* (Task 2.5 Disinfection Alternatives), Contract Number, conducted by the Orange County Water District. This report is entitled Disinfection alternatives in municipal wastewater reclamation. This project contributes to the Energy-Related Environmental Research program.

For more information on the PIER Program, please visit the commission Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's publication Unit at 916-654-5200

Executive Summary

The Orange County Water District (OCWD) has been involved in the reclamation of municipal wastewater for over twenty five years through the Water Factory 21 (WF21) reclamation facility. In an effort to meet increased demands for water in Orange County the current WF 21 facility must be expanded significantly. In order for expansion to be feasible using the current amount of land available new technologies must be considered. OCWD is planning to implement the Groundwater Replenishment System. This project would reclaim over 70 million gallons per day of secondary effluent using microfiltration, reverse osmosis, and ultraviolet (UV) disinfection. This project would replace the current WF 21 facility. The use of UV disinfection is still relatively new in the United States and has not been done on this scale. This research aims to gain information on the effectiveness of different UV technologies for the disinfection of various water qualities.

Background

The focus of this research was ultraviolet disinfection. UV irradiation is a technology that has proven to be effective for disinfection of various water sources. The advantages to the use of UV disinfection are numerous. Among the advantages are: no chemicals are used, eliminates the need for storing hazardous chemicals such as gaseous chlorine, potentially harmful disinfection byproducts are not formed, cost effective when compared to chemical-based alternatives, requires minimum operator attention and labor. This research focused on the use of a low pressure-high intensity, open channel UV system, collimated beam apparatus, and a pulsed UV system for inactivation of various microorganisms.

Objectives

The objectives of this research were:

- Evaluate the low-pressure high-intensity open channel UV system known as the TAK 55, manufactured by Wedeco-Ideal Horizons, using the "Proposed UV Disinfection Testing Protocol to Demonstrate Compliance with the California Reclamation Criteria" in order to meet Title 22 standards.

- Determine the efficiency of UV disinfection for inactivation of protozoa.

- Establish dose curve for pulsed UV and compare the performance of pulsed UV for disinfection of microorganisms using various water matrices.

Project Approach

Evaluation of Wedeco-Ideal Horizons TAK 55 System

The Wedeco-Ideal Horizons TAK 55 low pressure-high intensity UV system was set up at the OCWD Green Acres Project (GAP) facility. The GAP facility is an eight million gallon per day tertiary treatment plant that uses flocculation and dual media filtration followed by chlorination to treat secondary effluent for non-potable reuse. The TAK 55 system was set up to receive water after the dual media filtration process just upstream of the chlorination process. This set up enabled the effectiveness of the UV disinfection process to be compared with an approved chlorination process. The system was run continuously for four weeks and the effluent was sampled at various times for total

coliform concentrations. Following this testing the system was fed with 6000 to 8000 gallon batches of water seeded with coliphage MS2 virus indicator organisms. Several batch tests were run in which influent and effluent samples at various irradiation doses were taken. In addition all doses run on the TAK 55 system were also run on a collimated beam apparatus in the laboratory for comparison.

Efficiency of UV for Protozoa Inactivation
Three different collimated beam apparatus were used to evaluate the effectiveness of UV for inactivation of Giardia muris (G. muris) and Bacillus subtillus (B. subtillus). The three collimated beam apparatus used were a low pressure, low intensity; low pressure, high intensity and pulsed. Both G. muris and B. subtillus were irradiated at various doses using various water qualities. The irradiated samples were sent to an outside laboratory, Biovir Laboratories, for analysis using mouse infectivity assays.

Evaluation of Pulsed UV
A pulsed UV system from Innovatech was evaluated for the disinfection of various microorganisms using various water qualities. The pulsed UV system used consisted of an eight inch diameter vessel r that contained a single lamp located parallel to the flow of water. The pulsed UV chamber was first set up to receive secondary effluent as the feed water source. This UV system was designed for use on drinking water but had never been evaluated for use on wastewater. The system was run continuously and sampled on occasion for total coliform concentrations. In parallel to the eight inch treatment vessel was run a bench scale flow through test chamber. This test chamber serves the same function as a collimated beam apparatus for conventional UV systems. The test chamber allows for various doses of UV to be tested on a bench-scale basis using small batches of water. The test chamber was used to establish a dose-response curve that would aid in the choice of doses to be run on the eight inch vessel to achieve the desired level of disinfection. Other water sources including deionized and reverse osmosis effluent water were run through the treatment chamber. In addition the test chamber was run using various water seeded with coliphage MS2 virus indicator organisms.

Project Outcomes

Evaluation of Wedeco-Ideal Horizons TAK 55 System
The TAK 55 system was found to be most effective when used with three banks in series. This system worked best when the flow rate was limited to 17 gpm / lamp to achieve a four log reduction in coliphage MS2 on water with a transmittance of 55 % or less. The system proved to be successful in meeting the criteria established by State of California Title 22 Wastewater Reclamation Criteria.

Efficiency of UV for Protozoa Inactivation
The use of collimated beam apparatus proved that UV is effective for inactivation of protozoa species including Giardia muris and Bacillus subtillus. A four log reduction of G. muris was achieved on all three collimated beam apparatus evaluated at a dose of 5 mWsec / square cm. A four log reduction of B. subtillus was achieved on all three collimated beam apparatus evaluated at a dose of 80 mWsec / square cm. It was found that the low pressure, high intensity collimated beam apparatus was most efficient but that all three systems were equally effective.

Evaluation of Pulsed UV

The pulsed UV system was originally designed to treat surface water sources, but was shown to be successful for the disinfection of treated wastewater. The addition of a baffle system to the pulsed UV eight inch diameter treatment vessel proved to be key to the system's effectiveness. This baffle allowed for better flow through characteristics ensuring that all of the water to be treated would come in close contact with the pulsed UV lamp. A four log reduction in total coliform on secondary effluent was achieved at a UV dose of 80 mWsec / square cm. The theoretical dose calculated using the test chamber was compared with the doses used on the eight inch diameter treatment vessel. The correlation factor between the two systems was found to be 0.9 or 90% for the inactivation of total coliform in secondary effluent.

Conclusions and Recommendations

Conclusions

Ultraviolet disinfection is an important technology for reclamation projects. Advances in ultraviolet technology have allowed for the technology to become viable in today's regulatory climate including for the use in municipal wastewater reclamation. This project was successful in demonstrating three objectives:

- Low- pressure, high-intensity open channel UV systems were effective for meeting California's Title 22 reclamation criteria.
- Ultraviolet technologies of varying types: pulsed, low pressure-high intensity, and medium pressure were effective for the inactivation of protozoa.
- Pulsed UV technology had comparable effectiveness to conventional UV for the disinfection of various microorganisms in various water matrices.

Recommendations

Evaluation of Wedeco-Ideal Horizons TAK 55 System

The testing of the Wedeco-Ideal Horizons TAK 55 lamp technology has proven that this technology is viable for meeting the disinfections standards set by the California Title 22 guidelines for wastewater reclamation. It is recommended that this system be considered for use in future or current municipal reclamation projects. For current installations this system can replace or enhance disinfection systems currently in place. Many applications currently use chemical disinfection with chlorine as the primary disinfectant.

Efficiency of UV for Protozoa Inactivation

Tests need to be run using G. *muris* as an indicator organism for evaluation on a pilot scale UV system without having to lower the transmittance to an unreasonable level. It is also necessary to find a way to keep the G. *muris* from sticking to the plastic batch tank and the plastic PVC pipes which are connected at the influent and effluent ends of the pilot UV units.

Evaluation of Pulsed UV

The next step that should occur would be to test the pulsed UV 8” diameter pilot unit on membrane treated wastewater. The pulsed UV technology seems better fitted toward cleaner water sources. Several wastewater reclamation projects use membrane processes upstream of UV to improve the effectiveness of the UV system.

Abstract

The main objective of this research was to evaluate various ultraviolet technology systems. In particular their effectiveness for use in municipal wastewater reclamation was investigated. Low pressure, high intensity UV technology from Wedeco-Ideal Horizons, known as TAK 55, was evaluated for use in meeting California Title 22 Reclamation criteria for disinfection. This technology was successful for disinfection of tertiary effluent using testing outlined in the National Water Research Institute Guidelines. Various UV technologies were tested on a bench scale and full-scale basis to show their efficiency for inactivation of protozoa. Bench scale studies used collimated beam apparatus for testing. All UV technologies tested were proven to be successful for inactivation of protozoa at very low UV doses. Pulsed UV technology is relatively new and has not been used extensively. This research investigated the effectiveness of this technology for inactivation of various microorganisms in various water matrices. Pulsed UV was shown to be successful for inactivation of microorganisms of various types. The water matrix had a direct effect on the amount of UV dose needed for inactivation. Cleaner waters such as membrane treated sources required less UV dose for inactivation than did poorer water quality sources (such as secondary wastewater effluent).

1.0 Introduction

1.1 Background and Overview

The focus of this project was ultraviolet (UV) disinfection. UV irraditation is a technology that has proven to be effective for disinfection of various water sources. The advantages to the use of UV disinfection are numerous. Among the advantages are: no chemicals are used, eliminates the need for storing hazardous chemicals such as gaseous chlorine, potentially harmful disinfection byproducts are not formed, cost effective when compared to chemical-based alternatives, requires minimum operator attention and labor. The Orange County Water District (OCWD) is planning to construct a large-scale wastewater reclamation facility known as the Groundwater Replenishment (GWR) System .The proposed GWR System would use microfiltration, reverse osmosis, and UV disinfection to treat secondary treated wastewater to drinking water quality. The treated water would then be used for a seawater intrusion barrier and for surface spreading to replenish a local groundwater aquifer.

The use of UV disinfection for municipal reclamation is a relatively new in California. The oldest operating UV disinfection plants are less than twenty years old. Chlorine addition has been the dominant form of disinfection in the United States. Wastewater reclamation in California is regulated by the California Department of Health Services (DHS) under Title 22, Division 4, Chapter 3 of the California Code of Regulations (frequently referred to as Title 22). Title 22 criteria do not discuss UV disinfection , but allow alternative disinfection procedure that are demonstrated to be equivalent to Title 22 criteria. UV disinfection has been accepted by DHS as an equivalent technology provided certain guidelines are met. In recent years UV technologies have evolved rapidly and now use various types of UV lamps. The configurations and intensity of UV lamp systems are constantly being improved by manufacturers. UV lamps types include low pressure –high intensity, medium pressure, and pulsed. In order for OCWD to make an informed decision on what type of UV system to use for the GWR System several UV systems must be tested. The UV system eventually chosen for the GWR System would have to have acceptance from California DHS. It is hoped that this project will allow for evaluation of various UV systems for their effectiveness in disinfecting several types of organisms.

1.2 Project Objectives

1.) Evaluate the low-pressure high-intensity open channel UV system known as the TAK 55, manufactured by Wedeco-Ideal Horizons, using the "Proposed UV Disinfection Testing Protocol to Demonstrate Compliance with the California Reclamation Criteria" in order to meet Title 22 standards.

2.) Determine the efficiency of UV disinfection for inactivation of protozoa.

3.) Establish dose curve for pulsed UV and compare the performance of pulsed UV for disinfection of microorganisms using various water matrices.

1.3 Report Organization

The following report presents information collected from both pilot and bench scale investigations. The project approach contains information on the equipment

specifications and operational protocols while detailed results for the three parts of this project are presented in section 3.0 project outcomes. Finally, the conclusions and recommendations section contains a summary of the major results, an evaluation of the potential for commercialization, an estimate of the need for further work and an assessment of the benefits of the research for California.

2. Project Approach

2.1 Evaluation of Wedeco-Ideal Horizons TAK 55 System

Effluent disinfection at the OCWD Green Acres Project (GAP) Title 22 wastewater reclamation plant is currently achieved by chlorination. The GAP receives up to 7.5 million gallons per day of influent from the adjacent Orange County Sanitation District (OCSD) Plant 1. The OCSD Plant 1 provides secondary treatment, and the GAP provides filtration and disinfection to meet the California Wastewater Reclamation Criteria (CWRC).

The current UV guidelines adopted by the California DHS in 1993 are based on the UV technology tested at that time, which employed low-pressure, low-intensity mercury vapor UV lamps with flow parallel to the lamps in nonpressurized channels.

Proposed UV disinfection systems that do not conform to this base UV technology (such as Wedeco-Ideal Horizons) are known as "nonconforming UV systems." These systems may be acceptable to DHS if it can be demonstrated that they provide a degree of treatment and reliability at least equal to systems that have been shown to be acceptable to DHS.

As a low-pressure, high-intensity UV system, the Wedeco-Ideal horizon UV equipment requires testing to demonstrate its effectiveness at meeting the requirements of the CWRC. The study documented in this report tests the disinfection effectiveness of the Wedeco-Ideal Horizons UV system on the GAP filter effluent.

A schematic diagram of the pilot facilities is shown in Figure 1. The UV disinfection pilot plant was located adjacent to the GAP filters. The pilot system used for this project included three Wedeco-Ideal Horizon model TAK 55 UV banks, arranged in a straight flow configuration. Each bank included four TAK 55 lamps, complete with self-cleaning and intensity monitoring system. The UV banks are installed in an open channel in a straight flow configuration.

As shown in Figure 1, the pilot plant included a mix/batch tank upstream of the UV pilot system. The mix/batch tank was used to allow mixing of the seed, adjustment of UV transmittance, and elimination of fluctuations in the UV influent water quality, as discussed in the following sections. The tank had a usable volume of about 8,000 gallons, which allows preparation of an adequate volume of seeded UV influent for a complete test run. Unchlorinated filtered effluent from the filter effluent channel was pumped to the mix/batch tank. The UV pilot effluent was returned to the GAP filters. A summary of the facilities sizing for the UV pilot plant is presented in Table 1.

The UV dose was varied by either changing the lamp power set, by changing the flow rate, or by changing the number of UV banks activated. The desired flow rate was calculated based on measured UV transmittance, number of in-line units active, and the lamp power set.

Pilot testing was conducted from October 1999 through July 2000. Pilot plant operation, sampling, and water quality analyses were carried out by the OCWD staff. The engineering consulting firm of CH2M HILL was responsible for the development of the pilot test protocol and for overall technical direction and data analyses.

The pilot testing was conducted to determine the Wedeco-Ideal Horizons UV disinfection system efficiency and to develop the dose/response curves for the study microorganisms. In each test "run," a minimum of four doses was applied for development of the dose response curve. The UV dose was varied by changing the flow rate or the lamp power set point. The maximum pilot unit flow rate depends on the number of UV banks online. Table 2 presents the range of flows used in this pilot study for two and three bank operation.

The influent to the UV pilot unit was prepared in an 8,000-gallon mix/batch tank. Two adjustments were made to the UV influent: (1) UV transmittance was adjusted using a UV inhibitor compound (instant coffee); and (2) the UV influent was seeded by mixing coliphage MS2 with the tank contents to achieve a minimum UV influent coliphage level of about 10^6 plaque forming units per milliliters (pfu/mL). This coliphage level was necessary to demonstrate virus inactivation. Pilot system influent water quality was determined from a composite sample of three samples collected at the beginning, middle, and end of each test run.

In addition, a collimated beam test was conducted on the UV influent composite sample for each test run. The collimated beam test was conducted at four doses. The collimated beam test results were compared with the results of the pilot test unit.

The UV influent transmittance was typically in the range of 60 to 65 percent. Therefore, the addition of a UV transmittance inhibitor was required to reduce the influent UV transmittance to less than 55 percent.

In our previous studies, brewed and instant coffees were tested to determine their effectiveness in reducing UV transmittance in the spectral range desired for this study. Both brewed and instant coffees were found to be effective at increasing UV absorbance consistently across the UV light spectra of 200 to 300 nanometer (nm). Instant coffee was selected for use in the UV pilot study since it is easier to handle.

The pilot study included seeded experiments with coliphage MS2. Controlled influent concentrations of coliphage MS2 were prepared by mixing the coliphage seed with the batch tank of GAP filter effluent to achieve target concentrations of 10^6 pfu/mL. To allow for complete mixing of the seed with the tank contents, the seed was added when the tank was half full. Following seeding, the recirculation pump was started and the tank was filled. After the tank reached the desirable level, the contents were mixed for an additional 30 minutes, then pumped to the UV pilot unit for testing.

Microorganisms monitored in this pilot study included indigenous total coliform and both indigenous and seeded coliphage MS2. Coliphage MS2 was used as the virus indicator for establishing the 4-log virus inactivation. Coliphage MS2 has been proposed as a model for enteroviruses in UV disinfection studies.

2.2 Efficiency of UV for Protozoa Inactivation

The Giardia *muris* (G. *muris*), Bacillus *subtillus* (B. *subtillus*), and coliphage MS2 seed was grown by Biovir Laboratories, Inc. and then sent to the Orange County Water District overnight in a cooler. The seed was refrigerated immediately and used within 24 hours of receipt to insure its viability. Filtered Milli-Q Ultrapure deionized (DI) water was used with the seed to reduce any interference with the G.*muris*. This is important because it was found that G.*muris* is extremely sticky and will grab onto constituents in the water, causing inconsistent and inconclusive results. The same water was used with the B. *subtillus* and coliphage MS2 for comparison purposes. Also, the B. *subtillus* seed is cloudy and when combined with low transmittance water, the resulting transmittance was too low to be representative of reclaimed water. The Ultrapure DI water is filtered through a 0.2 micron filter and then seeded with the organisms. The target concentration of the influent solution was 1×10^6 for G. *muris* and 1×10^7 for B. *subtillus* and coliphage MS2. The B. *subtillus* and the coliphage MS2 were combined together in filtered Ultrapure DI water to make an influent solution.

The G. *muris* was added to each petri dish, which already contained the filtered Ultrapure DI water. The volume of the G.*muris* seed and the filtered Ultrapure DI water together is 50ml, which makes a sample depth of 1cm. Standard sized plastic petri dishes (100 x 15 mm) were used, which needed to be rinsed with a Tryptic Soy Broth solution in order to keep the G. *muris* from sticking to the dish. G. *muris* does not stick to glass so the pipets used did not need to be rinsed with Tryptic Soy Broth. The influent solution was placed under the collimated beam and exposed to UV light for the time appropriate for each dose. A volume of 50 ml of the combined B. *subtillus* and coliphage MS2 influent solution was added to each standard sized petri dish. Each petri dish was then placed under the collimated beam and exposed to UV light for the time appropriate for each dose. In order to calculate the exposure time for each sample, the intensity of the UV light coming out of the collimated beam must be measured at the surface of the sample and around the entire surface area of the sample in the petri dish using an International Light 1400A radiometer. The dose was calculated using the following formulas:

$$D=I_0t[(1-e^{-kd})/kd]$$

Where:

D = UV dose at 254 nm ($mW\text{-}s/cm^2$)

t = Exposure time (seconds)

I_0 = Incident intensity at the surface of the sample (mW/cm^2)

k = Absorbance coefficient (cm^{-1}) (Note that this is base e)

d = Depth of the sample (cm).

The incident intensity was multiplied by 0.975 to account for the 2.5% surface reflectance at the surface of the sample.

The transmittance was converted into absorbance with the following formula:

$$k = -\ln (T/100)$$

Each sample was transferred into a sterile container and properly sealed and labeled. The entire sample load was then sent to Biovir Laboratories, Inc., along with travel controls for G. *muris*, B. *subtillus*, and coliphage MS2, and the necessary paper work. BioVir Laboratories received the samples within 24 hours for analysis.

The stock organism, Giardia Muris, Robert Dobson Strain (originally acquired from Frank Shaffer,US EPA Cincinnati OH), was acquired from the Oregon State Health Labs, Corvallis, Oregon. In order to ensure that the G. *muris* was of sufficient quality, cysts were tested within one week of collection. Typically, the cysts were harvested from mice on a Monday; enumerated by hemocytometer at BioVir Laboratories, Inc. on the following Tuesday, and tested at OCWD on Wednesday or Thursday. Cysts were received back at BioVir by Friday. The animals were inoculated by Monday or Tuesday.

Individual samples were enumerated by hemocytometer counts to confirm the number of cysts. Dilutions were made based upon the hemocytometer counts in order to show 2, 3, 4, and in some cases, 5 log removals. Twenty day-old BALBc mice were supplied by Simonsen Laboratories in Gilroy, CA. Three to five mice were used per dilution per sample.

Based upon the concentration of cysts in the sample, an appropriate volume of sample was fed to the mice using stainless steel feeding tubes. Mice were fed approximately, 100, 1,000, 10,000 and 100,000 cysts in groups ranging from two individuals (for positive controls) to five individuals for samples. Mice were housed by inoculation group and maintained for 10 to 14 days.

At the end of the incubation period, each mouse was placed individually into a beaker. Fecal droppings from each mouse were recovered and placed into a 1.5 mL sterile centrifuge tube. The feces were emulsified in sterile phosphate buffer. Approximately 50 µL of the fecal suspension was placed onto coated glass multi-well slides. The specimens were fixed with methanol, washed, rinsed and stained with Mur- A-Glo (Waterborne, Inc., New Orleans, LA) , a *G. muris* specific FITC-labeled antibody stain.

Slides were observed under epifluoresence microscopy. *G. muris* were identified by their reaction with the FITC-labeled antibody stain (bright green), shape (ovoid) and size (ranges 9 - 15 µm). Any slide well that contained fecal material with > 10 *G. muris* was counted as a positive. The number of mice demonstrating an infection was tallied within each dilution set in an indicated number format.

Controls included: 1. A positive stock control on the freshly received material, 1000, 10,000 and 100,000 organisms per animal set; 2. Positive travel control on the stock material sent to OCWD, typically 1000, 10,000 and 100,000 organisms per animal set; 3. Negative control with pasteurized stock organisms, 100,000 pasteurized organisms per animal set; 4. Negative control with buffer water diluent.

Bacillus *subtilus* (ATCC 6633) spores were cultivated, harvested and washed at BioVir Laboratories, Inc. as described in ASTM 966.04 (BioVir Modification)[1]. Spores were shipped to OCWD via overnight delivery on ice. Upon arrival at BioVir laboratories, Inc., dilutions of the samples were made in APHA buffered water[2]. Samples and dilutions were analyzed by the pour plate method in Trypticase Soy Broth Agar and

incubated for 48 hours at 35°C[2]. Following incubation, colonies were counted and concentrations (per mL) were calculated based upon the dilution factors.

Male-specific (MS) phage type 2 (ATCC 15597-B1) was cultivated and prepared in accordance with USEPA Method 1602 (proposed)[3]. Coliphage MS2 were shipped to OCWD via overnight delivery on ice. Upon arrival at Biovir laboratories, Inc., dilutions of the samples were made in Trypticase Soy Broth. The host bacteria, E. coli (ATCC 15597) was prepared the day of inoculation. The single agar overlay method, USEPA Method 1602 (proposed)[3], was used to enumerate the phage.

2.3 Pulsed UV

The first three steps of the test plan for pulsed UV water treatment require the use of the Innovatech SPECIAL TEST CHAMBER known as the "flow through test chamber". (Shown schematically in Figure 2). Innovatech, therefore, provided its own chamber for the first three steps:

Step 1: Develop a "Dose vs Distance" curve for OCWD waters (i.e. OCWD water in the chamber between the EPES lamp and the Joule Meter).

Figure 3 shows the "Pulsed UV Intensity (UV dose/pulse) vs Distance from the Lamp for Various Waters". Include are; (1) a composite curve from numerous previous tests using clear tap water, (2) the results using the OCWD water labeled "tap water do not drink", (3) Deleware County Ohio tertiary effluent, (4) Fort Wayne Indiana secondary effluent, and (5) the results from using the OCWD secondary effluent (bottom curve in blue). As noted, in comparison, the Intensity vs Distance for the OCWD secondary effluent is reduced considerably, probably due to the high turbidity and other UV absorbing elements in the water. Nevertheless, these are the actual physical conditions that exist. Consequently, this data was then used to accomplish Step 2, as follows:

Step 2: Develop an "Inactivation vs Dose" curve for the microorganisms in the OCWD waters.

Flowing water tests had to be used instead of static testing using cuvettes, since 100 ml samples were required for assay purposes. (The flowing water portion of the Special Test Chamber shown in Figure 2 was used). The water to be tested is allowed to flow through the pulsed UV test chamber and is irradiated at several doses. The concentration of microorganisms left is then determined for each dose . A graph is plotted of the concentration of microorganisms left after irradiation versus the irradiation dosed. This curve is known as a dose-response curve for the pulsed UV.

Figure 4, is a composite graph of the "Inactivation (Number of Organisms Remaining) vs Total UV Dose" for the OC Waste Water Plant Effluent. As noted, inactivation of up to four (4) Logs required a dose of approximately 80 mWs/cm^2 . Total coliform bacteria were tested for in this case.

Step 3: Determine a "Weighted Pulsed UV Dose/Pulse" (WD/P) for the conditions determined above, in the Treatment Chamber.

Although the initial calculations were done for the eight inch diameter chamber, it was found after some testing, that the low UV transmittance and the low flow rates did not produce acceptable treatment conditions for this water in an eight inch diameter chamber. Therefore, Innovatech developed a baffle system that effectively reduced the diameter of the chamber to five inches. The calculated/theoretical WD/P for a five-inch diameter chamber, using the intensity vs distance values from Figure 3, was determined to be 4.48 mWs/cm^2

Step 4: Determine the Approximate Number of Pulses that will be required to reduce the Microorganism count to the desired value. (Four logs or a count of 100 was desired for total coliform inactivation).

By using the Total Dose of 80 mWs/cm^2, from Figure 4, as the dose necessary to accomplish a four (4) Log reduction, and the calculated WD/P value of 4.48 mWs/cm^2 for the eight inch diameter chamber baffled down to a five inch diameter, we would expect that approximately 18 pulses (80/4.48) would be required in the treatment chamber, to accomplish the desired four (4) Log reduction in total coliform.

Step 5: Conduct Testing in the Treatment Chamber to determine the Actual Inactivation vs Number of Pulses to achieve a Four Log Reduction.

As indicated above, after numerous unsuccessful attempts to get consistent results with the high turbidity/low UV transmissivity waste water and the low flow conditions, Innovatech devised a baffle system that effectively reduced the chamber diameter to five inches. With the baffles to facilitate mixing and the shorter path length for the UV, the treatment consistency and effectiveness improved dramatically. As shown in Figure 5, 20 pulses were actually required to reduce the number of organisms remaining after treatment to 100 (four log reduction).

Step 6: Determine the Actual Dose per Pulse in the Chamber.

Using the Dose of 80 mWs/cm^2 (as shown in Figure 4), required to reduce the number of organisms after treatment by four logs (to 100 organisms), and the actual number of pulses (20) to accomplish this same reduction, (see Figure 5), it was determined that the Actual Dose per Pulse in the chamber was ~4 mWs/cm^2 (80 mWs cm^2 /20 pulses).

Comparing the actual/measured Dose/Pulse value of 4.0 mWs/cm^2 with the calculated/theoretical WD/P value of 4.48 mWs/cm^2 indicates a "Chamber/Mixing Efficiency" of ~90%. Future calculations for a WD/P would be reduced by this factor, if it were not possible to do an actual test to determine the Actual Dose Per Pulse for the water in question.

This six-step procedure was done for secondary effluent water as well as for tertiary effluent from the OCWD GAP plant. The 8" diameter pulsed UV system pilot unit was tested on secondary effluent for a total of approximately eight months from October 1998 to June 1999. Figure 6 shows the 8" diameter pilot unit.

It was not originally planned to test the pulsed UV 8" diameter pilot unit system on secondary effluent since this system is designed for drinking water applications. It was intended that the system would only be tested on tertiary effluent, microfiltered effluent

and reverse osmosis effluent. Due to a lack of available tertiary, microfiltered, and reverse osmosis effluent secondary effluent was chosen. Testing on secondary effluent provided a more challenging matrix to treat because of higher suspended solids and turbidity concentrations. Once the tertiary effluent source became available from the OCWD GAP plant the pilot system was tested on that source water. Finally, a series of tests were conducted using the flowing test chamber, which is similar to a collimated beam device for continuous wave UV. Filtered DI water, reverse osmosis effluent, and tertiary effluent were seeded with coliphage MS2 and run through the flowing test chamber. The tests run with filtered DI water were also seeded with Bacillus Subtillus. These tests were run in order to establish a range of doses for which the pulsed UV system would be effective in disinfecting coliphage MS2. These tests allowed the pulsed UV process to be evaluated without going through the trouble and expense of running the 8" diameter pilot unit.

3. Project Outcomes

3.1 Evaluation of Wedeco-Ideal Horizons TAK 55 System

For pilot testing, the GAP effluent was diverted to the mix/batch tank, upstream of the UV pilot plant. To adjust the UV transmittance to less than 55 percent and coliphage concentration to more than 10^6 pfu /mL, coffee and coliphage seed were added and mixed with the tank contents. To establish the UV influent quality, three samples of mix/ batch tank contents were collected at the beginning, middle, and end of each UV pilot test run. A composite sample was prepared from these three samples and used for establishing the UV influent quality and for conducting the collimated beam test. A summary of the water quality data is presented in Table 3. As shown in Table 3, the turbidity of the UV influent exceeded 1.0 nephelometric turbidity unit (NTU) and ranged from 1.2 to 2.2 NTU.

For pilot testing, a total of 15 test runs was conducted. During the first six test runs, it was also realized that the quartz sleeves supplied with the pilot unit were defective. The sleeve surface was warped and was not uniform. This defect resulted in surface deposits, fouling of the quartz sleeve, and non-uniform UV light emission. The impact of the quartz sleeve defect and fouling on UV intensity available for disinfection, light emission/distribution, and the overall performance of the system cannot be assessed. Therefore, after the sixth run, the quartz sleeve and the UV lamps were replaced. Nine test runs were conducted with the new quartz sleeves.

The summary of UV transmittance influent and effluent coliphage for each test run is presented in Table 4. In Run No. 4, the UV transmittance was measured at 45 percent compared to the target value of 55 percent. Therefore, this test run was excluded from this analysis.

Collimated beam tests serve as the standard against which the pilot test results can be compared. The collimated beam apparatus used for this study was supplied by Wedeco-Ideal Horizons. This collimated beam unit used three low-pressure, low-intensity UV lamps and was equipped with an adjustable sample tray, a pneumatically operated shutter for automatic adjustment of the exposure time, and an intensity monitor. The collimated

beam unit was warmed for a minimum period of 10 minutes before testing. An International Light (IL) model IL 1400A Radiometer was used to measure the UV intensity at the sample surface. This direct reading was used to calculate the UV dose.

Figures 7 and 8 present the results of the collimated beam test Run Nos. 7 through 15 for UV doses in the range of 20 to 150 millijoules per centimeter squared ($mJ/cm^{2)}$. Collimated beam test, using coliphage MS2, should be performed and compared to published curves to ensure that the test results are consistent and comparable to other similar studies. The results of collimated beam results conducted by various researchers were recently reviewed by the DHS. Based on this review, a range for acceptable collimated beam results was established. Figure 7 presents the quality assurance/quality control of the collimated beam results. This figure compares the collimated beam results with the area bound by the following two formulas, which define the range of acceptable results:

$$\left|\log(N/N_o)\right| = 0.040 * [\text{UV dose, } mJ/cm^2] + 0.64$$
$$\left|\log(N/N_o)\right| = 0.033 * [\text{UV dose, } mJ/cm^2] + 0.20$$

Where:

N = concentration of infective MS-2 after UV exposure, and

N_o = concentration on infective MS-2 at dose zero

As shown in Figure 7, the majority of the collimated beam results (>80 percent) fall within the limits shown. Therefore, the collimated beam procedure and results deemed validated and acceptable. Figure 8 presents the regression analysis of the collimated beam results for the dose range of 20 to 150 mJ/cm^2, including the data points outside the area bounded by the above formulas. The curve plotted in Figure 8 was used to establish the delivered dose for the pilot unit.

Coliphage inactivation results for Run Nos. 1 through 9 (excluding Run No. 4) are presented in Figures 9 through 11. Figures 9 and 10 present the results for lamp power output set at low level (70 percent) and Figure 11 presents the results for lamp power output set at high level (100 percent). As shown in Figure 9, the Run No. 2 results, which were conducted with two banks, are significantly better than all other results. The results from this run were excluded and the results were replotted. The results of the pilot study for low lamp power-set, excluding Run No. 2, are presented in Figure 10.

As shown in Figures 10 and 11, the performance of the pilot unit improves for three-bank operation compared to two-bank operation. With three banks online, the pilot unit was able to achieve 4-log MS2 inactivation at a flow rate of 17.2 gpm/lamp and 12 gpm/lamp for high and low power sets, respectively. The ratio of these low to high power set flow rates (12/17.2) is 0.70, which is in line with the anticipated ballast output (0.7). Similarly, with two banks online, the flow rates for 5-log inactivation were 11.3 gpm/lamp and 7.7 gpm/lamp for high and low power set, respectively. The ratio of the low to high power set flow rates was 0.68.

The delivered dose results for the pilot unit are summarized in Table 5. The delivered UV dose is defined as an assigned dose having the same germicidal effect as a measured dose in a laboratory-scale collimated beam reactor equipped with a low-pressure, non-ozone-producing mercury lamp. The delivered dose was established by comparing the pilot plant log inactivation results to the collimated beam results. The delivered UV doses are presented in Figure 12.

3.2 Efficiency of UV for Protozoa Inactivation

Project Outcome for protozoa testing

Three different collimated beams were compared in performance of inactivation of Bacillus *subtilus* spores. Coliphage MS2 was also tested on the collimated beam units as a standard for comparison. Three types of UV collimated beams tested are low-pressure low-intensity made by UC Davis, PCI Wedeco – Ideal Horizons low-pressure high-intensity and Innovatech pulsed UV system. The low–low and low-high UV collimated beam units have monochromatic lamps which outputs at a wavelength of 254nm. The low-low collimated beam unit has two 40 W lamps and the low-high collimated beam unit has four 300 to 400 W lamps. The pulsed UV system contains 10,000 to 50,000V, polychromatic, flash lamps, which have an output ranging from 200 to 300 nm. Figure 13 illustrates the UV dose needed to achieve log removal of Bacillus subtilus spores. Figure 14 illustrates the UV dose needed to achieve log removal of MS2 phage.

Inactivation of G. *muris* was tested on the Wedeco – Ideal Horizons low-pressure high-intensity, UC Davis low-pressure low-intensity, both described previously described, and the Aquionics medium-pressure high-intensity UV collimated beam units. The Aquionics medium-pressure high-intensity collimated beam unit has 1,000 to 30,000 W lamps which have a polychromatic output from 200 to 300 nm. Table 6 illustrates the log removal of G. *muris* from the three different UV collimated beam units. Based on the results from the collimated beam testing, which showed that a 4-log inactivation of G. *muris* is achieved at a dose of 5 mWs/cm^2, along with previously discussed issues of sticking, we ruled out testing on a pilot scale UV unit. Achieving a dose of 5 mWs/cm^2 and below on our available pilot scale UV units, based on the manufacturers flow chart, would require an unrealistic transmittance adjustment. The water would no longer be representative of reclaimed water quality and the results would be inconclusive. Even with a large transmittance adjustment, the pipes connecting to the pilot UV unit would not have the capacity for such high flows.

3.3 Pulsed UV

The Innovatech pulsed UV system was designed for use on drinking water. It was thought this technology had potential for use on waters of lesser quality than drinking water. For this reason it was decided to test the pulsed UV pilot system on secondary effluent. Pulsed UV is capable of introducing large amounts of energy into water over a short period of time, which is ideal for treated wastewater. Secondary effluent contains large numbers of bacteria along with measurable turbidity and suspended solids. It was decided that measuring for removal of total coliform would be a good way to measure the effectiveness of the pulsed UV pilot unit. Secondary effluent was fed to the pilot unit and various UV doses were applied. The doses applied were suggested by Innovatech in order to establish a baseline for the dose necessary to achieve a four-log reduction in total coliform concentration. A four-log reduction in total coliform was suggested as the target removal. Eleven separate tests were run and results of those tests are presented in Table 7. The average concentration of total coliform in the secondary effluent source was 1,000,000 CFU/100 mL. The initial tests were not successful and it was determined that the low flow rates being tested were causing hydraulic short-circuiting in the 8" pilot unit chamber. The flow rate the pilot unit was designed to treat for could not be obtained at the OCWD test facility. Innovatech installed a baffle plate on the inlet to the pilot unit

chamber, which forced the water to flow closer to the lamp and eliminate some short-circuiting. The installation of the baffle plate allowed for a four-log reduction in total coliform to be achieved using a dose of 80-100 mJ/cm^2 for secondary effluent. After the eight month test period on secondary effluent the pilot unit was tested on tertiary effluent from the OCWD GAP plant. This water had a slightly lower total coliform concentration than the secondary effluent and a lower turbidity as well. The pulsed UV system was able to achieve a four-log reduction in total coliform at a lower dose when tested on the GAP plant effluent. This is due to the superior water quality of the GAP plant effluent. The results of three separate tests are shown in Table 8. It appears that a dose of 40 to 50 mJ/cm^2 resulted in four-log reduction in virus for the tertiary effluent source water.

Finally, the pulsed UV flow-through test chamber was evaluated for disinfection of coliphage MS2. The coliphage MS2 testing was done using the flow-through test chamber first in order to establish whether the pulsed UV technology was effective for removal of these microorganisms. The flow-through test chamber allowed for several water sources to be tested easily without using large amounts of water and coliphage MS2 seed. Figure 15 shows the results of the coliphage MS2 testing for various water sources. Previous testing using continuous wave UV showed that a four-log reduction in coliphage MS2 could be achieved using a dose of about 100 mJ/cm^2. Testing with the pulsed UV flow through chamber showed that a four-log reduction in coliphage MS2 occurred at a dose of nearly 150 mJ/cm^2. Due to operational difficulties of the pulsed UV 8" diameter pilot unit coliphage MS2 seeded tests were not conducted using the pilot unit. The pilot unit treatment chamber began to have numerous leaks and was unable to run continuously without periodic maintenance. It was decided that any further seeded coliphage testing would not occur using the 8" diameter pilot unit.

4. Conclusions and Recommendations

4.1 Evaluation of Wedeco-Ideal Horizons TAK 55 System

Conclusions

The Wedeco-Ideal Horizons pilot unit, using TAK 55 lamp technology, was pilot tested at OCWD using GAP filter effluent. The study included seeded studies with MS2. The UV transmittance of the GAP water was reduced to less than 55 percent using coffee. Collimated beam tests were also conducted on the UV influent samples using a low-pressure, low-intensity collimated beam unit. Based on the results of Wedeco-Ideal Horizons Pilot unit equipped with TAK 55 lamp technology it can be concluded that:

- The TAK 55 technology is capable of achieving 4-log MS2 inactivation.
- The pilot plant performance improved when the number of banks online was increased from 2 to 3 banks.
- The MS2 inactivation results tracked the lamp power set. At low power set, the flow per lamp was approximately 70 percent of the high power set.
- The maximum flow per lamp for achieving 4-log inactivation of MS2 was 12 gpm/lamp at low power set and 17.2 gpm/lamp at high power set for the filtered

effluent, with a UV transmittance of less than 55 percent and turbidity greater than 1 NTU.

- The pilot system was operated at a design water level of 210 millimeters (mm) (8.25 inches). At this water level, the maximum permissible headloss through the UV banks was 40 mm (1.57 inches).

Recommendations

- The testing of the Wedeco-Ieal Horizons TAK 55 lamp technology has proven that this technology is viable for meeting the disinfections standards set by the California Title 22 guidelines for wastewater reclamation. It is recommended that this system be considered for use in future or current municipal reclamation projects. For current installations this system can replace or enhance disinfection systems currently in place. Many applications currently use chemical disinfection with chlorine as the primary disinfectant.

Benefit to California

- The benefits to California are great as a result of this contract. The testing done as part of this contract could lead to certification of the Wedeco-Ideal Horizons TAK 55 technology by the California Department of Health Services for use in Title 22 reclamation applications. The certification of this technology leads to an increase in options for agencies in need of disinfection technologies for reclamation projects. Currently, the list of approved technologies is brief and the inclusion of this technology will add to the list options for disinfection.

4.2 Efficiency of UV for Protozoa Inactivation

Conclusions

- 4-log inactivation of B. *subtilus* spores was achieved at a dose of about 80 mWs/cm^2
- 4-log inactivation of G. *muris* was achieved at a dose of about 5 mWs/cm^2
- G. *muris* is extremely susceptible to sticking which can cause inconclusive results when not tested in a very controlled environment.

Recommendations

- A good next step would be to figure out how to run G. *muris* on a pilot scale UV system without having to lower the transmittance to an unreasonable level. It is also necessary to find a way to keep the G. *muris* from sticking to the plastic batch tank and the plastic PVC pipes which are connected at the influent and effluent ends of the pilot UV units.

Benefit to California

- Completing this project has benefited California in that it shows that low levels of UV radiation are able to disinfect harmful protozoa. This allows other agencies to use UV technology in place of conventional disinfection technologies, which may be more expensive or may create unwanted disinfection byproducts.

4.3 Pulsed UV

Conclusions

- The Innovatech Pulsed UV chamber in its present configuration was designed for "relatively clear" drinking water. The pulsed UV testing on the OCWD secondary effluent source provided an excellent opportunity to investigate the effectiveness of the current chamber design on waters with low UV transmissivity and high NTU levels. It was found that by introducing a baffle design to reduce the effective cross section and improve mixing within the chamber, it was possible to adapt this drinking water design to effectively treat the secondary effluent to the desired four log reduction, for a very reasonable dose level of 80 mWs/cm^2.

- The testing also allowed a comparison to be made between the Calculated/Theoretical Weighted Dose per Pulse and the Actual/Measure Dose per Pulse in the actual chamber. The Mixing or Efficiency ratio of 0.9 (90%) is considered to be a reasonable expectation for the chamber given the variables involved.

- Although the primary objective of testing the Innovatech Pulsed UV system at the Orange County test facility is to determine its applicability for treating the waste water, after the filtration and RO steps, and just prior to ground water re-injection, the Phase I tests on the secondary effluent provided an excellent opportunity to learn more about the system and introduce improvements.

- The testing using the special test chamber for flowing water testing showed that the use of pulsed UV for coliphage MS2 removal in tertiary effluent was not as effective as continuous-wave UV.

Recommendations

- The next step that should occur would be to test the pulsed UV 8" diameter pilot unit on membrane treated wastewater. The pulsed UV technology seems better fitted toward cleaner water sources. Several wastewater reclamation projects use membrane processes upstream of UV to improve the effectiveness of the UV system.

Benefit to California

- The benefits to California from this project are that there is now evidence to show that pulsed UV technology can be applicable to disinfection for reclamation applications.

References

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2. American Public Health Association, American Water Works Association, and Water Environment Federation. 1992. *Standard Methods for Water and Wastewater*. 18th Edition.

3. U.S. Environmental Protection Agency, 2000. Method 1602: Male-specific (F^+) and Somatic Coliphage in Water by Single Agar Layer (SAL) Procedure. Draft, April 2000. Office of Water, Washington, DC 20460.

Glossary

UV – Ultraviolet

OCWD – Orange County Water District

DHS – Department of Health Services

GWR System – Groundwater Replenishment System

GAP – Green Acres Project

OCSD – Orange County Sanitation Districts

CWRC – California Wastewater Reclamation Criteria

gpm – Gallons per minute

pfu/mL – Plaque forming units per milliliter

G. muris – Giardia muris

B. subtillus – Bacillus subtillus

NTU – Nephelometric Turbidity Units

cfu – Colony forming units

List of Figures

Figure 1 – Set Up of UV Pilot Plant

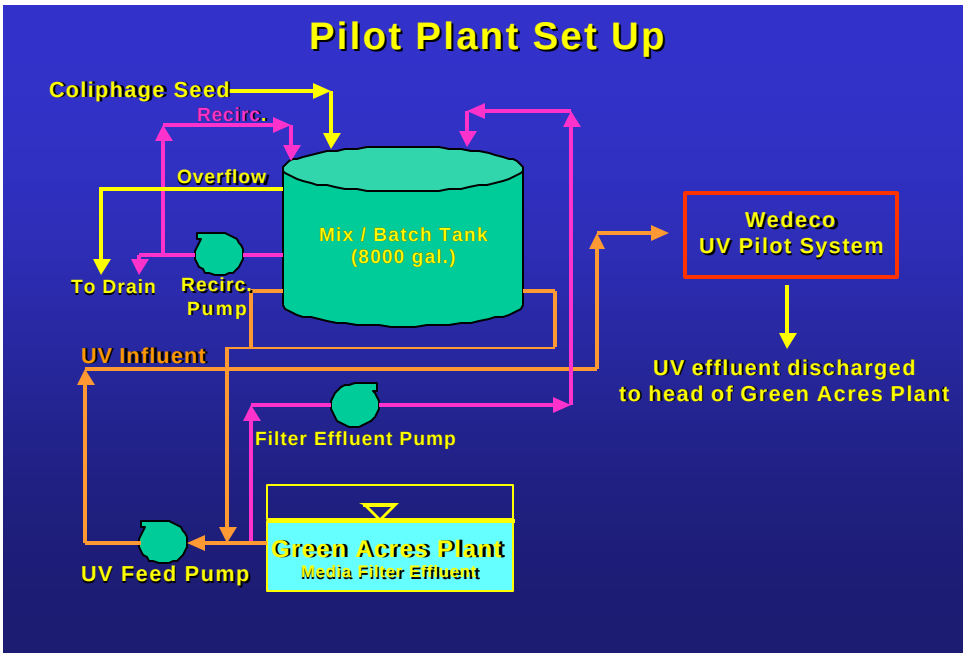


Figure 2 - Innovatech's Special Test Chamber for Flowing Water Testing. (Equivalent to a collimated beam device for continuous wave UV.)

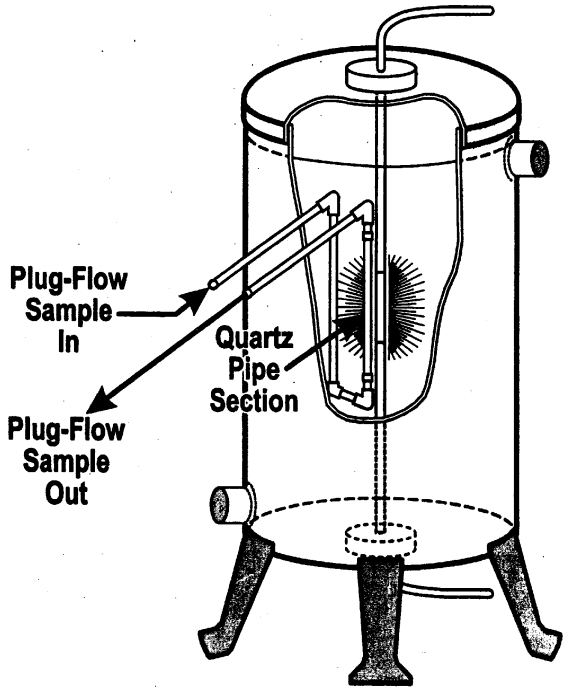


Figure 3 - Pulsed UV Intensity vs Distance From the Lamp for Various Waters

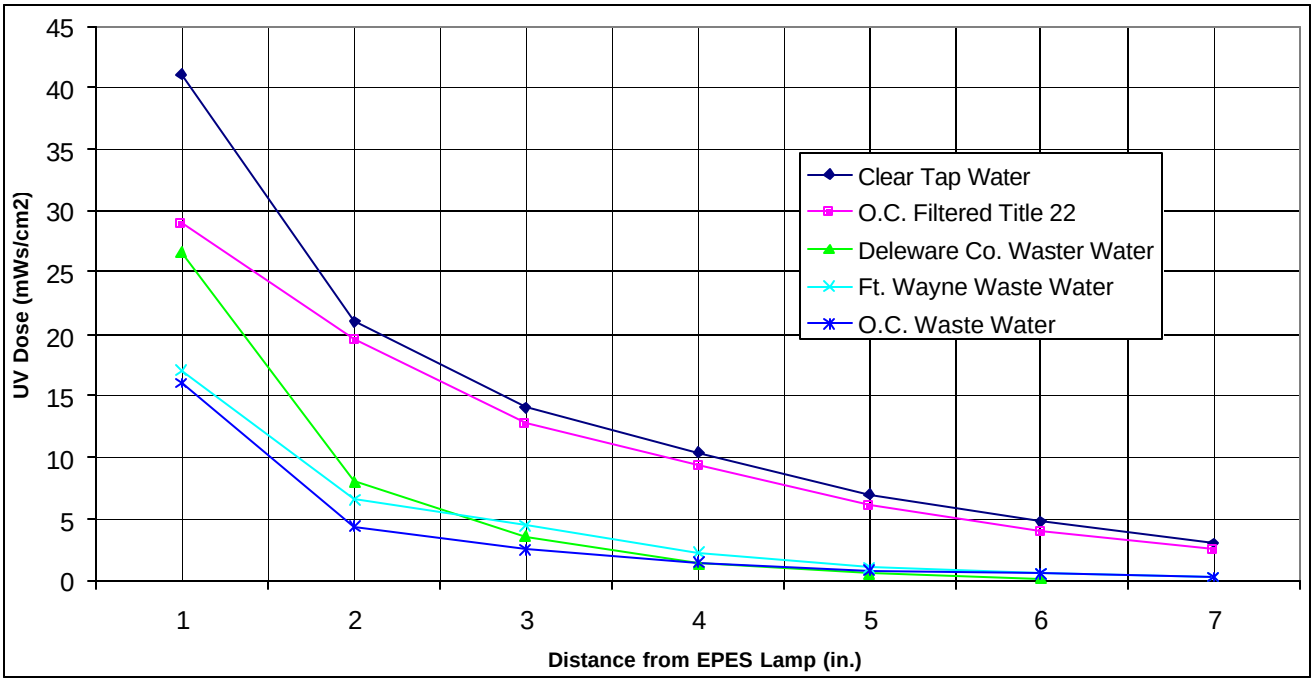


Figure 4 - Inactivation vs. Total UV Dose for OCWD Secondary Effluent

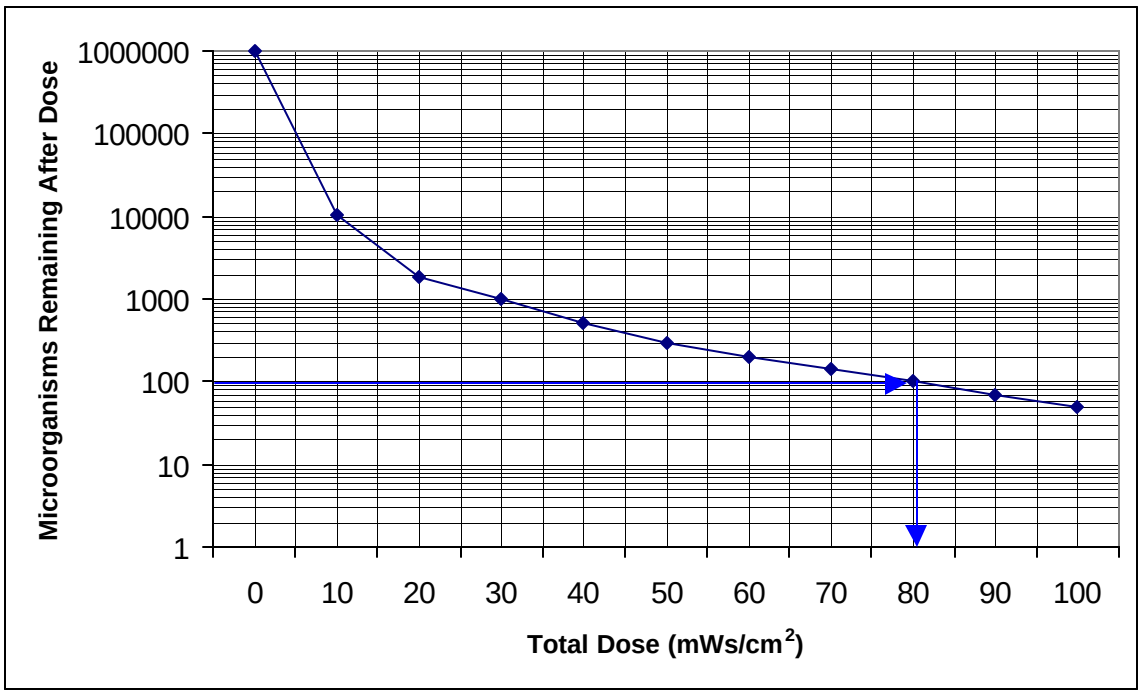


Figure 5 - Inactivation vs. Number of Pulses Treating the Chamber Volume

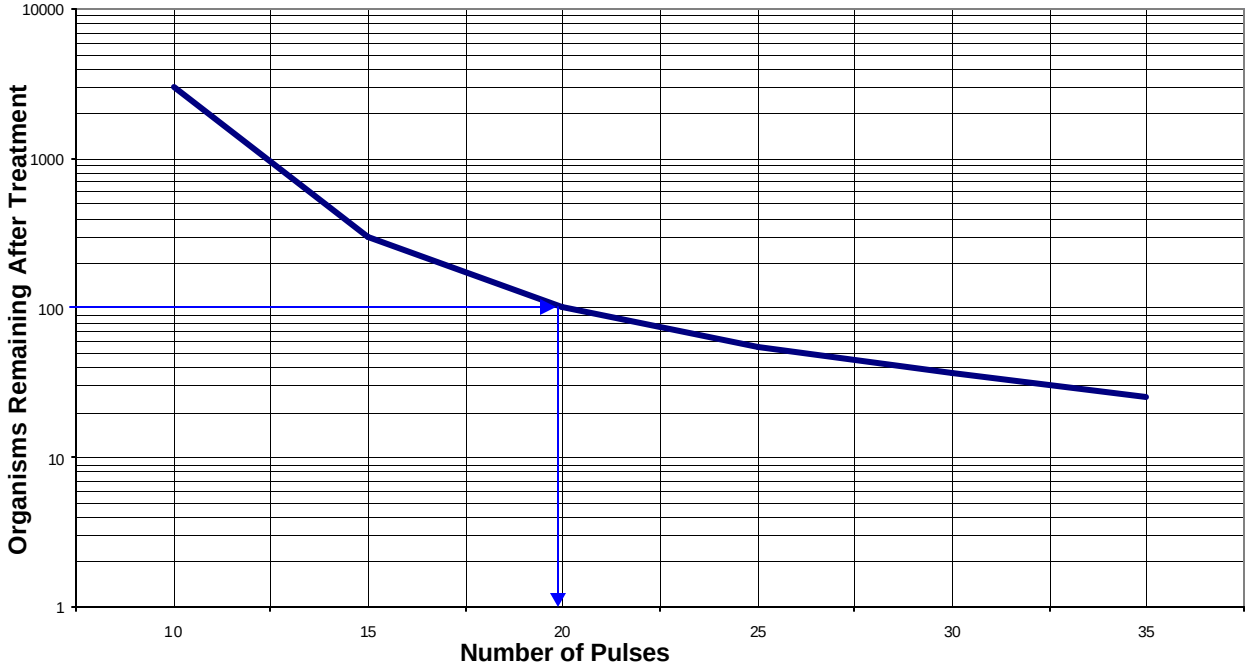


Figure 6 – Innovatech 8”diameter pulsed UV pilot unit.

Figure 7 - Validation of Collimated Beam Results

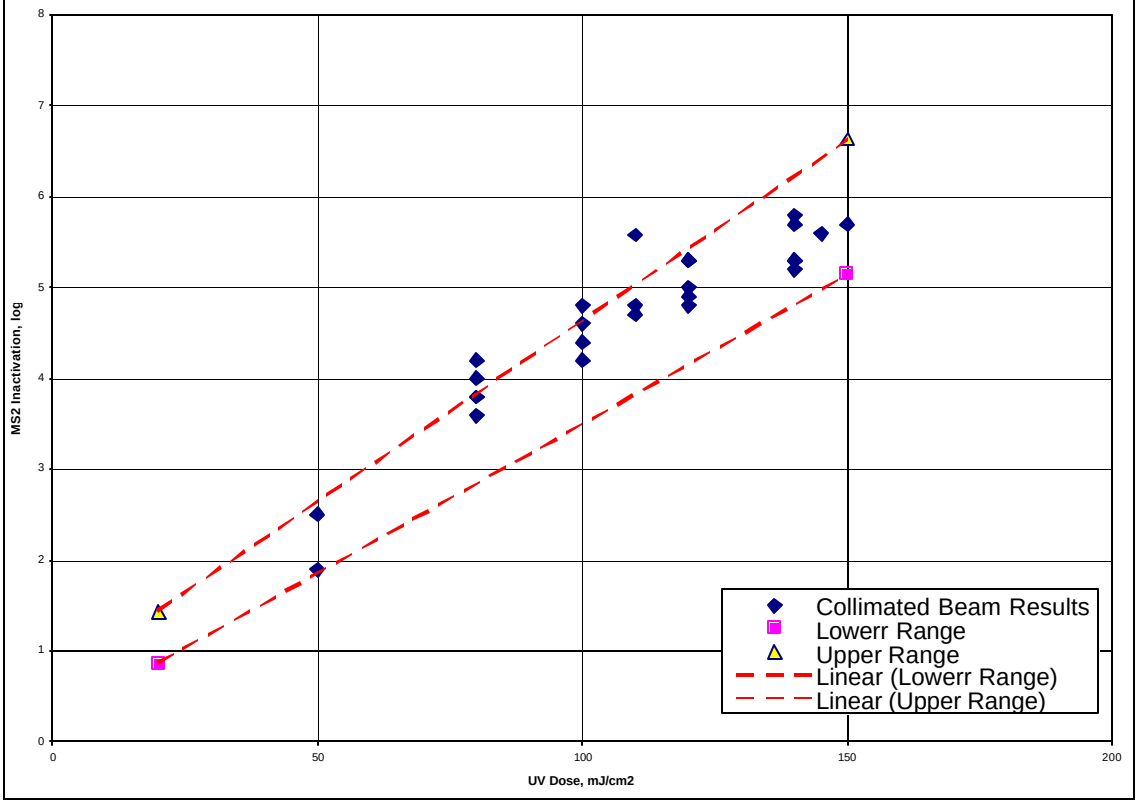


Figure 8 - Validation of Collimated Beam Results

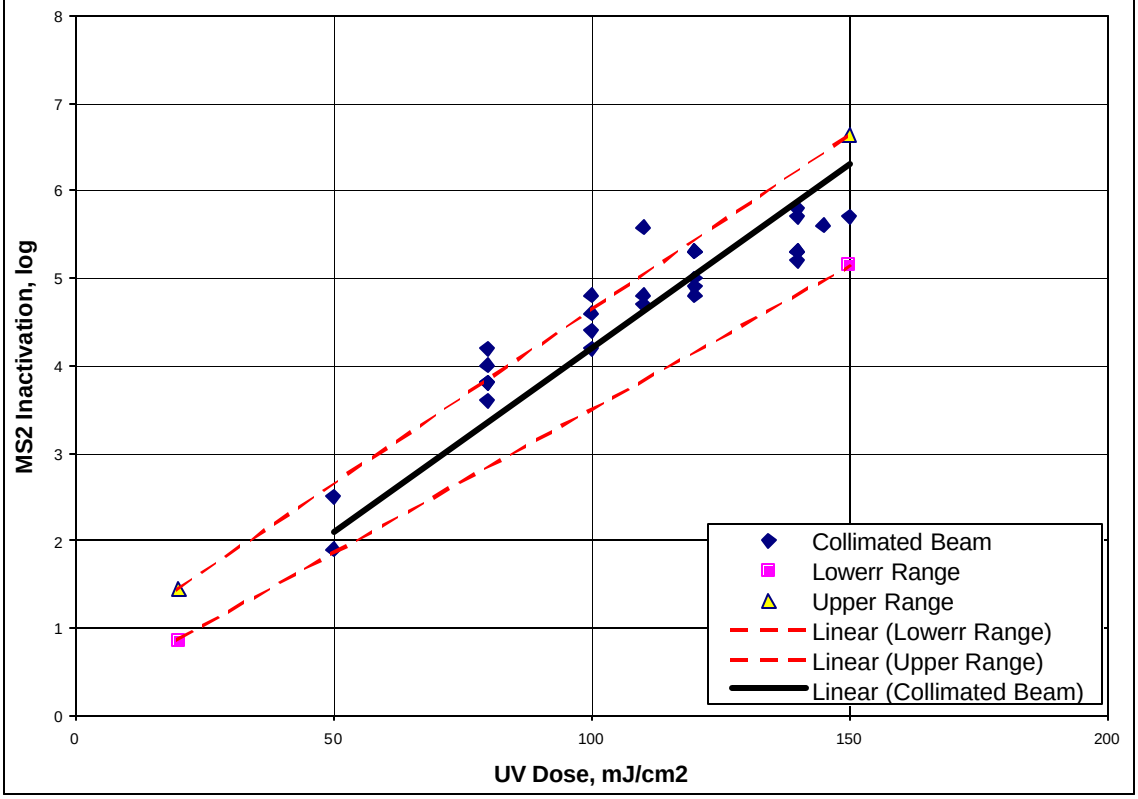


Figure 9 - MS2 Inactivation for Low Lamp Power

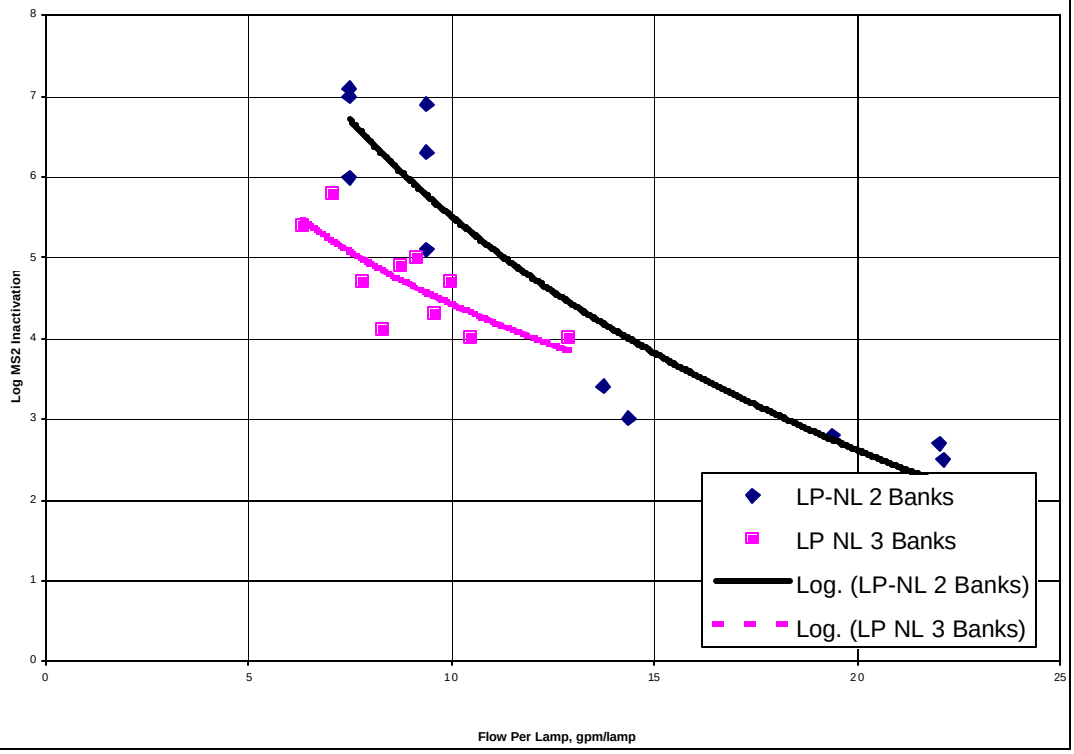


Figure 10- MS2 Inactivation for Low Lamp Power-W/O Run 8

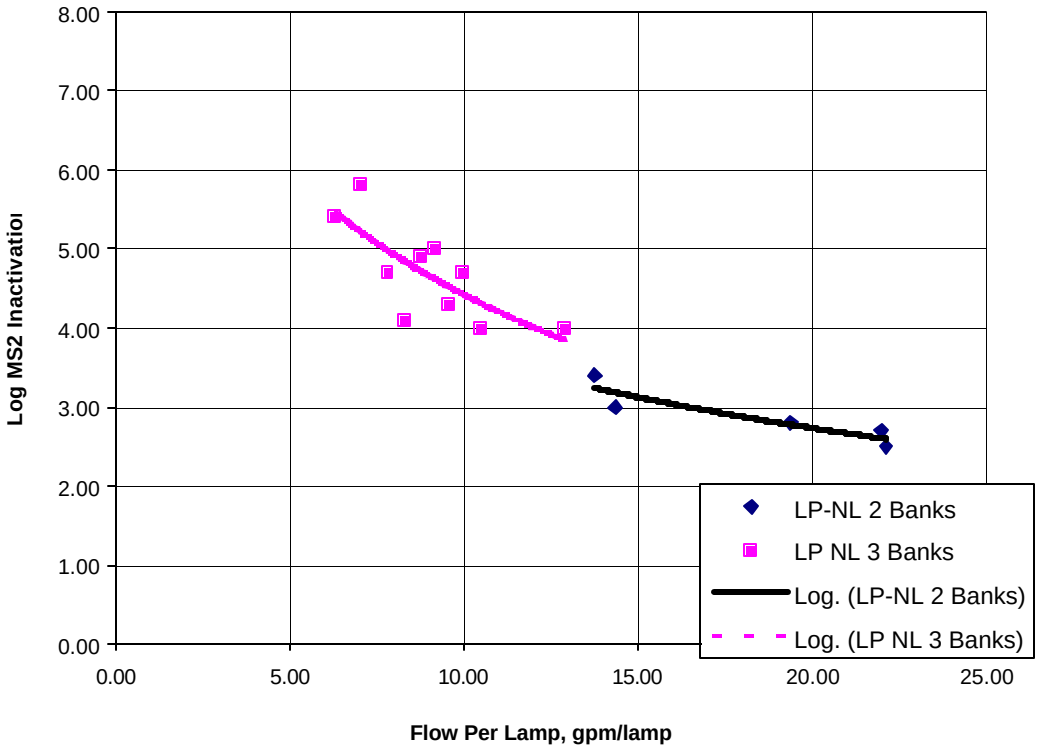
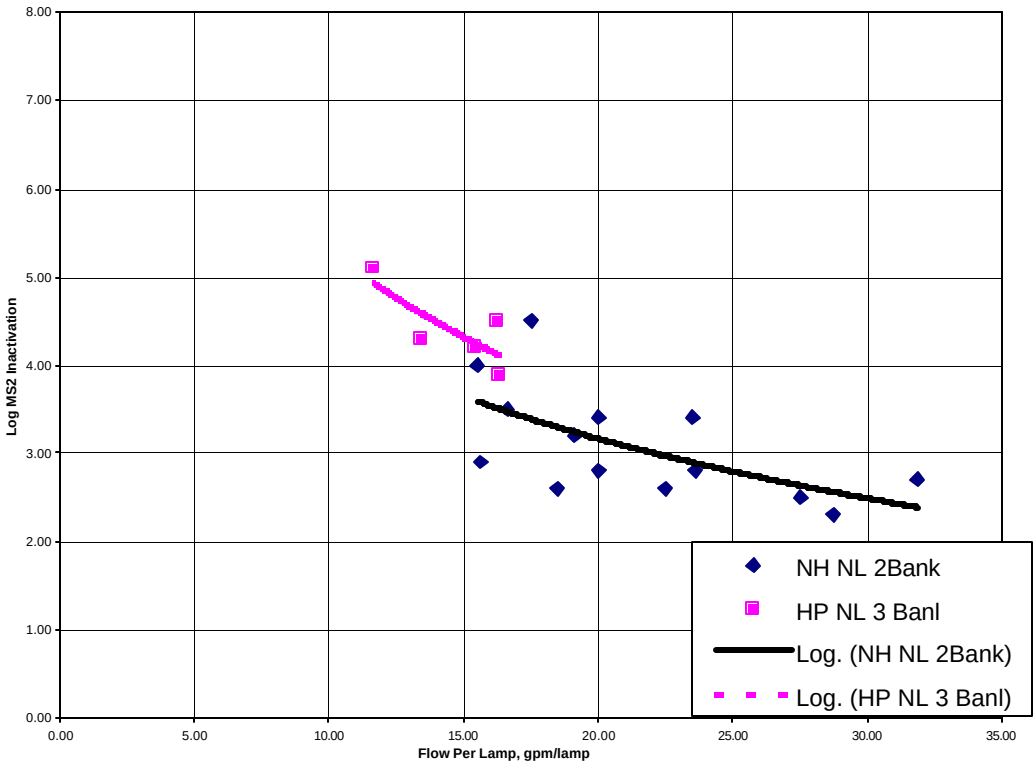


Figure 11 - MS2 Inactivation for High Lamp Power



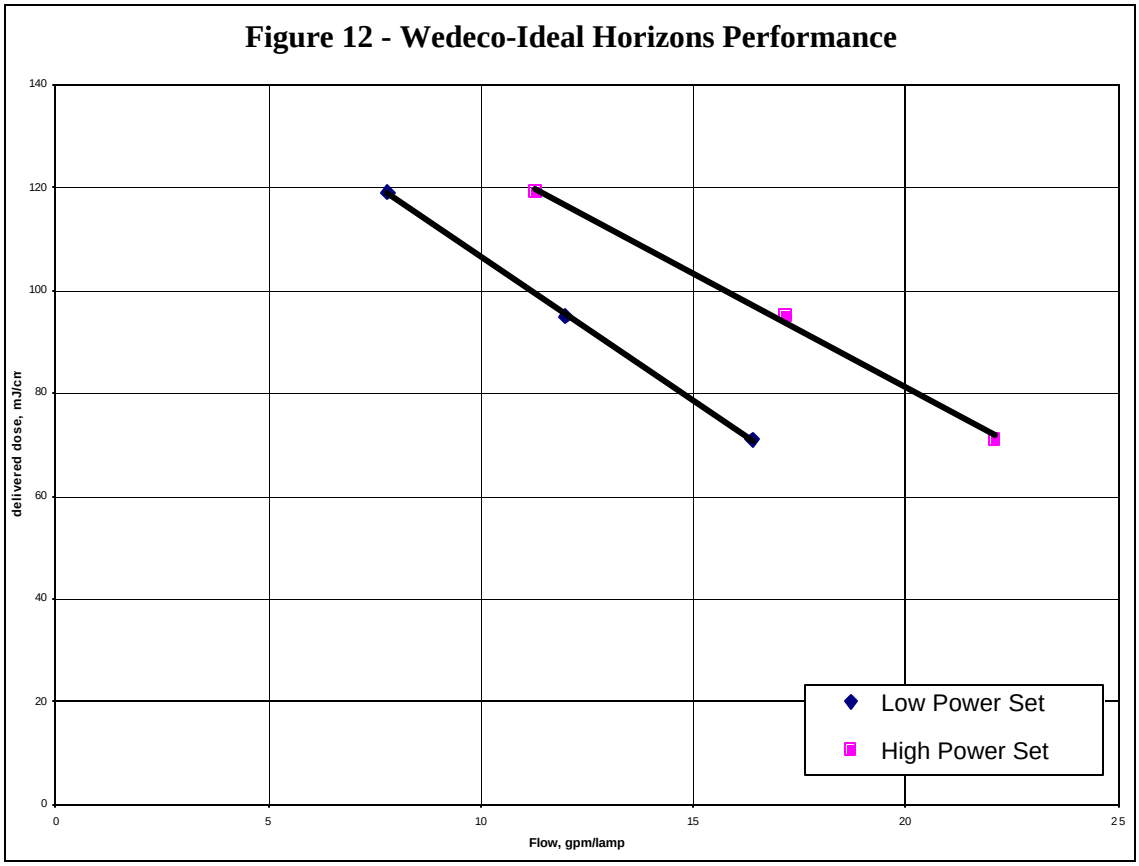


Figure 13 - Inactivation of Bacillus *subtillus* Using Various Collimated Beam Units

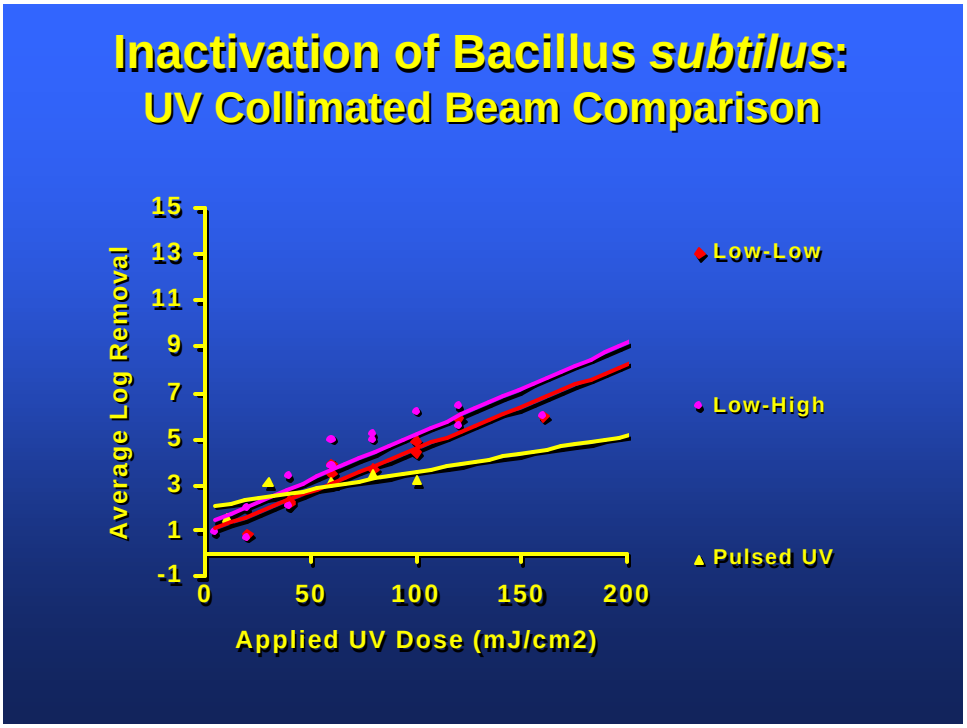


Figure 14 - Inactivation of Coliphage MS2 Using Various Collimated Beam Units

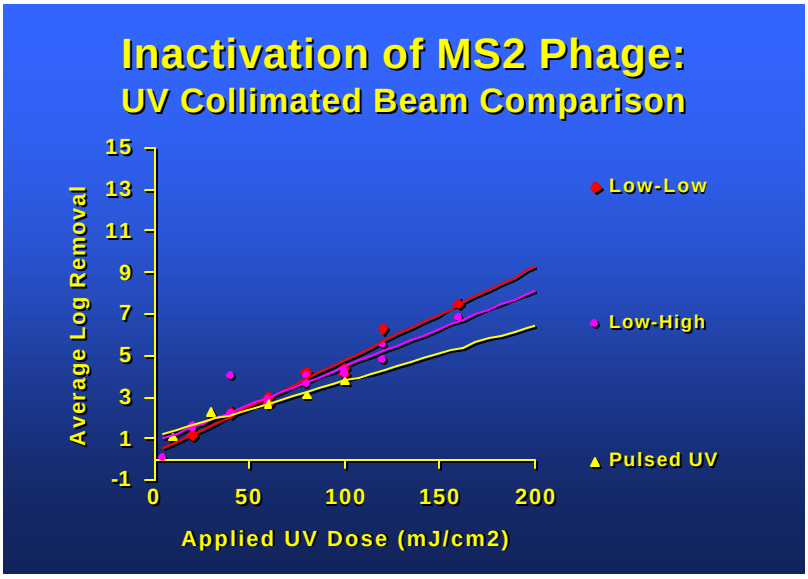
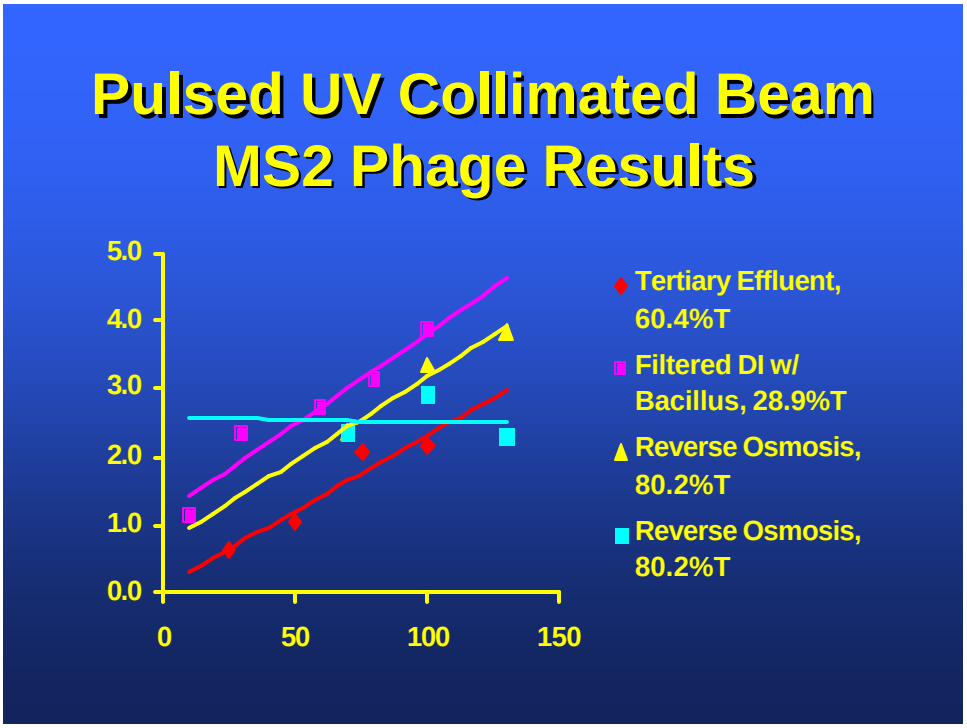


Figure 15 - Results of Coliphage MS2 Using Pulsed UV Special Flow Through Test Chamber



List of Tables

TABLE 1
UV Pilot Plant Facilities Sizing

Item	Unit	Value
Flow Rate		
UV influent (maximum)[a]	gpm	400
Mixing pump	gpm	100
Pipes and Valves[b]		
Filter Effluent	inch	6
UV Influent	inch	6
Recirculation	inch	3
Overflow	inch	3
Mix/Batch Tank (existing)		
Total volume	gallons	10,000
Maximum Operating Liquid volume	gallons	8,000
Recirculation Pump (existing)		
Capacity	gpm	100
TDH	ft	15
UV Pilot Feed Pump (existing)		
Capacity	gpm	800
TDH	ft	35

[a]Based on the pilot unit configuration, the maximum flow through the pilot unit was limited to 400 gallons per minute (gpm) maximum for the disinfection study.

[b]The pipe sizes shown are for the installed pilot plant facilities piping.

TDH = total dynamic head

TABLE 2
Headloss for TAK55 Pilot Plant

Flow		1 Bank			2 Banks			3 Banks		
In gpm	In m^3/h	Flow gpm/lamp	Headloss in inch	Headloss in cm	Flow gpm/lamp	Headloss in inch	Headloss in cm	Flow gpm/lamp	Headloss in inch	Headloss in cm
40	9.1	10.0	0.016	0.040	5.0	0.031	0.080	3.3	0.047	0.120
60	13.6	15.0	0.039	0.100	7.5	0.079	0.200	5.0	0.118	0.300
80	18.1	20.0	0.067	0.170	10.0	0.134	0.340	6.7	0.201	0.510
100	22.7	25.0	0.106	0.270	12.5	0.213	0.540	8.3	0.319	0.810
120	27.2	30.0	0.154	0.390	15.0	0.307	0.780	10.0	0.461	1.170
150	34.0	37.5	0.240	0.610	18.7	0.480	1.220	12.5	0.720	1.830
200	45.4	50.0	0.429	1.090	25.0	0.858	2.180	25.0	1.287	3.270
220	49.9	55.0	0.516	1.310	27.5	1.031	2.620	27.5	1.547	3.930
250	56.7	62.5	0.665	1.690	31.2	1.331	3.380			
270	61.2	67.5	0.776	1.970	33.8	1.551	3.940			
300	68.0	75.0	0.961	2.440						
385	87.3	96.3	1.579	4.010						

TABLE 3
Summary of Influent Water Quality Characteristics

Parameter	Range
TOC	11.7 to 22.1
TDS	854 to 978
Total Hardness	261 to 296
Total Alkalinity	237 to 256
Total Suspended Solids	<1 to 8.4
Turbidity	1.2 to 2.2
pH	7 to 8
Iron (µg/L)	110 to 220

Notes:

TOC = total organic carbon
TDS = total dissolved solids
µg/L = micrograms per liter

TABLE 4
Summary of Pilot Plant Influent

Test Run	UV Transmittance %	UV Influent MS2, pfu / mL
1	54.6	1.7×10^7
2	55.5	7.3×10^5
3	52.4	1.4×10^7
4	45.3	4.1×10^6
5	52.0	1.8×10^6
6	52.8	6.4×10^5
7	53.9	4.4×10^5
8	54.9	5.1×10^5
9	55.0	1.2×10^6

TABLE 5
Delivered UV Dose

Flow (gpm/lamp)	MS2 log Inactivation	Number of UV Banks Online	Delivered UV Dose (mJ/cm^2)
Low Power Set			
16.4	3	2	71
12.0	4	3	95
7.7	5	3	119
High Power Set			
22.1	3	2	71
17.2	4	3	95
11.3	5	3	119

Table 6 - Giardia *muris* Collimated Beam Results

DATE	UV SYSTEM TESTED	UV DOSE mWs/cm^2	CYST DOSE/ ANIMAL	RESULT # POSITIVE / # ANIMALS	LOG REMOVAL
11/19/99	PCI	0 (Infl)	5.00E+02	3/3	
		25	1.00E+04	0/2	**4**
		50	1.00E+04	0/2	**4**
		75	1.00E+04	0/2	**4**
1/13/00	PCI	0 (Infl)	6.00E+03	4/4	
		5	6.00E+03	2/4	**<3.77**
		20	6.00E+03	0/4	**>3.77**
		40	6.00E+03	0/4	**>3.77**
3/2/00	DAVIS	0 (Infl)	1.00E+04	4/4	
		5	1.00E+05	1/1	**<5**
		15	1.00E+05	1/4	**<5**
		20	1.00E+05	0/1	**5**
6/1/00	PCI	0 (Infl)	1.00E+05	2/2	
		5	1.00E+05	1/3	**<5**
		10	1.00E+05	0/3	**5**
		15	1.00E+05	0/3	**5**
	DAVIS	0 (Infl)	1.00E+05	2/2	
		5	1.00E+05	3/3	**<5**
		10	1.00E+05	3/3	**<5**
		15	1.00E+05	3/3	**<5**
	AQUIC	0 (Infl)	1.00E+05	2/2	
		5	1.00E+05	0/3	**5**
		10	1.00E+05	0/3	**5**
		15	1.00E+05	0/3	**5**
6/29/00	PCI	0 (Infl)	1.00E+05	5/5	
		5	1.00E+05	0/4	**4**
		10	1.00E+05	0/4	**4**
		15	1.00E+05	0/4	**4**
	DAVIS	0 (Infl)	1.00E+05	3/4	
		5	1.00E+05	0/4	**4**
		10	1.00E+05	0/4	**4**
		15	1.00E+05	0/4	**4**

Table 7 - Results of Total Coliform Testing on 8" Diameter Pulsed UV Pilot Unit Using Secondary Effluent

DATE	DOSE (mWs/cm^2)	TOTAL COLIFORM (pfu/100mL)
10/15/98	5.3	490000
	10.6	310000
	21	15000
	32	1200
	48	480
10/29/98	18	3800
	35	300
	53	180
	71	140
	99	100
1/11/99	30	38000
	60	> 200
	126	> 200
	180	> 200
	252	> 200
	300	> 200
1/12/99	50	> 200
	100	27
	150	26
	200	21
	250	25
	300	200
2/9/99	20	12000
	28	9300
	49	11000
	98	480
	148	1000
	197	620
	236	520
2/23/99	15 - 47	> 2000
	30 - 95	> 2000
	45 - 140	> 2000
	45 - 141	> 2000
	60 - 190	> 2000
	75 - 240	< 1
	150 - 472	1800
3/9/99	26	> 200000
	52	> 200000
	105	> 20000
	153	7300
	183	3800
	306	> 200
3/29/99	26	170000

	52	46000
	105	4700
	153	640
	183	300
	306	110
4/12/99	55	16000
	55	1700
	68	1300
	76	1000
	110	7900
	110	2600
	153	2100
	220	670
	300	140
6/7/99	0	> 2000
	31	150
	55	23
	73	63
	73	15
	73	91
	110	9
	147	7
	220	10
6/16/99	26	2419.2
	26	2419.2
	26	2419.2
	50	290.9
	50	648.8
	50	248.1
	88	38.8
	88	35.9
	88	28.8

Table 8 - Results of Total Coliform Testing on 8" Diameter Pulsed UV Pilot Unit Using Tertiary Effluent.

DATE	DOSE (mWs/cm^2)	TOTAL COLIFORM (pfu/100mL)
9/9/99	10	< 1
	21	< 1
	28	< 1
	42	< 1
	67	< 1
	84	< 1
	112	< 1
	168	< 1
9/21/99	5.2	13
	7.8	22
	11.2	2
	19.6	< 1
	19.8	6
	39.2	< 1
	41.6	< 1
	55.5	< 1
10/5/99	1.8	< 1
	5.4	< 1
	7	6700
	9.8	< 1
	11	8200
	14.5	< 1
	21	4500
	32.6	< 1